

Clouds and the Earth's Radiant Energy System (CERES)

Validation Document

Imager Cloud-Top Heights and Imager Cloud-Base Heights (Subsystem 4.2)

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4.2.1 Introduction

4.2.1.1 Measurement and Science Objectives

This document proposes a strategy for addressing the verification of cloud properties from EOS imager data, specifically cloud layering and cloud base and top heights. The methodology used to retrieve cloud boundaries from imager data are presented in Baum et al. (1995a). CERES cloud retrieval algorithms are currently in development using data from the Advanced Very High Resolution Radiometer (AVHRR, 1.1 or 4-km resolution at nadir), the High resolution Infrared Radiometer Sounder (HIRS, 17.4 km resolution at nadir), and various geostationary platforms such as the Geostationary Orbiting Environmental Satellite (GOES; 1-km visible, 4-km infrared). Beginning with the launch of the Tropical Rainfall Measurement Mission (TRMM) in 1997, the CERES algorithms will be applied to data from new imagers, including the Visible-Infrared Radiometer (VIRS, 2-km resolution) and the Moderate Resolution Imaging Spectroradiometer (MODIS; 0.25, 0.5, and 1-km resolution). While we designed the CERES cloud algorithm to have as input any imager data, a number of questions remain as to how consistent the cloud retrievals are between the various imagers. Besides the differences in spectral channels between imagers, there is also a difference in pixel resolution to consider. In the following sections, we propose a number of strategies, in order of priority, for verifying cloud boundary properties.

4.1.2.2 Missions

The first launch of the CERES instrument is on the Tropical Rainfall Measurement Mission (TRMM) in 1997. In 1998, CERES will launch on the EOS-AM-1 platform, followed by EOS-AM-2. Follow-on missions to TRMM and EOS-AM and EOS-PM are currently planned. The CERES algorithms will be applied to data from new imagers, including the Visible-Infrared Radiometer (VIRS, 2-km resolution) and the Moderate Resolution Imaging Spectroradiometer (MODIS; 0.25, 0.5, and 1-km resolution).

4.1.2.3 Science data products

The cloud properties generated from imager data in CERES Subsystem 4.1, 4.2, and 4.3 will be convolved with CERES broadband radiometric data and saved in the CERES SSF product.

4.2.2 Validation Criterion

4.2.2.1 Overall approach

Our validation strategy involves two key elements. First, our retrieved cloud properties must be consistent globally for both daytime and nighttime conditions. Second, assuming our cloud prop-

erties are consistent and reasonable on a global scale, we need to verify that the results compare well with independent observations from ground-, air-, or other satellite-based observations.

Several methods are available for implementing steps to address the first key element. Proof of consistency may be found, for example, from inspection of global maps of derived cloud parameters, from comparison with previous results for some specified time period, or by comparison with other global cloud products such as the International Satellite Cloud Climatology Project (ISCCP) or Clouds from AVHRR (CLAVR). It is our experience that inspection of raw imagery and global cloud property maps, especially during the initial processing stages, tends to uncover a multitude of problems. While some problems may be easily tracked down, others may indicate more subtle algorithm implementation problems. Each imager has idiosyncrasies that take time to understand. Once the imager is better understood, software needs to be developed and implemented to work around those idiosyncrasies. Global, gridded cloud products may be generated automatically during processing. To some degree, comparison with time histories of previously generated results may also be automated. Comparison with other data sets such as ISCCP or CLAVR are more time intensive, especially concerning the interpretation of differences between various data sets.

Once the behavior of the imager used to develop CERES cloud properties is understood and the retrieved cloud properties seem to be consistent globally, comparison of cloud boundaries will be made with independent observations. Comparison of satellite-retrieved cloud properties with ground-based observations should be performed over a long time period for a number of regions, as we will discuss later in this document.

4.2.2.2 Sampling requirements and trade-offs

We will organize the satellite cloud height retrievals by cloud type over the globe. If a field campaign studies cirrus intensively over the midlatitude United States, will the information be relevant for the midlatitude regions in Asia, the Tropics or poles? For a first cut at relevant cloud types, we can define the following categories:

- a. Cloud types: low, middle, high, and multiple layer
- b. Surface types: ocean (Tropics, midlatitude, and polar), vegetated land (Tropics and midlatitude), non-vegetated land (deserts, other), mountains, snow-covered land (midlatitude and polar), ice-covered water
- c. Seasons: summer, winter, transition
- d. Day/night: We have not made separate categories for twilight or sunglint conditions. The twilight zone includes data retrieved under conditions of solar zenith angle between 85° and 90° . If algorithms depend on NIR channels, the solar contribution, while small, will preclude the nighttime algorithm assumption. Sunglint absolutely can not be ignored for overpasses over water and deserts.

With this set of categories, there are a total of $4 \times 11 \times 3 \times 2 = 264$ conditions. We can reduce this number of conditions to 264 by forcing the CERES cloud algorithm to use only IR channels for twilight and sunglint conditions, but cloud height retrievals may not be smooth at the boundaries between sunglint/non-sunglint regions and day/night transition regions. If we further assume that we need 100 independent samples for each of the conditions, we require $100 \times 264 = 26,400$ samples.

4.2.2.3 Measures of Success

The CERES cloud retrieval team intends to discern whether each satellite imager (i.e., AVHRR, MODIS, VIRS) pixel contains none, one, or multiple cloud layers. We consider validation to be completed when the uncertainties have been determined to be within the accuracies shown in Table 1 over all major surface types for the full range of applicable viewing angles at all times of day.

The all-purpose algorithm for cloud-top height detection is the Layered Bispectral Threshold Method (LBTM), which now is employed globally. The LBTM approach will work with VIRS, MAS, MODIS, AVHRR, GOES-8, and GOES-9 data. For mid- to high-level clouds, we also employ the CO₂ slicing method using radiometric channels within the 15-micron CO₂ band. The 15-micron channels are available on the HIRS, MAS, GOES, and MODIS instruments, but not on AVHRR or VIRS. Over ocean surfaces, the spatial coherence method is being used for cloud-top height determination of large cloud decks. Determination of cloud layering for the Version 1.1 cloud algorithm is being accomplished using two different techniques: spatial coherence and pattern recognition via a fuzzy logic approach. Our goal is to obtain the desired accuracies shown in Table 1.

Table 1: Current and desired accuracies for cloud-top and cloud-base pressure retrievals.

Parameter	Current Accuracy (hPa)	Desired Accuracy (hPa)
Cirrus cloud-top pressure: a. LBTM b. CO ₂ slicing	a. 50 b. 50	a. 25 b. 25
Cirrus cloud-base pressure: a. LBTM	a. 60	a. 50
Mid-level cloud-top pressure a. LBTM b. CO ₂ slicing	a. 50 b. 50	a. 25 b. 25
Mid-level cloud-base pressure a. LBTM	a. 50	a. 50
Low cloud-top pressure: a. LBTM b. Spatial coherence	a. 50 b. 50	a. 25 b. 25
Low cloud-base pressure: a. LBTM	a. 25	a. 25

4.2.3 Pre-launch Algorithm Test/Development Activities

4.2.3.1 Field experiments and global studies

In Section 4.2.2.1, we mentioned that the first step in the process of verification is to make certain that the global cloud properties are consistent on a global scale for both daytime and nighttime retrievals. Some basic questions are listed below:

1. Are cloud heights consistent moving from day to night?
2. Are cloud heights consistent at nadir and at high-viewing angles?
3. Are certain regions displaying large changes in cloud heights between successive over-passes?
4. Are cloud heights consistent even though the surface type may change in the region? For instance, if the surface changes from desert to water or from water to ice, do cirrus cloud heights change across the boundaries?

These are just a few examples of the type of question that must be answered to be able to have some degree of confidence in the results.

To summarize, basic global verification processes include:

- Internal consistency checks (e.g., view zenith angle dependence of results and day-to-day cloud cover results)
- Global and regional analyses of cloud parameter statistics over long time periods
- Comparisons to existing climatologies and data sources (ISCCP, CLAVR, surface observations)

Once some confidence has been gained in processing global imager data, the next task is to compare the results to independent observations. There are numerous problems involved in comparing satellite-derived results with ground-based lidars or radars. For instance, one must account for the relatively small size of the lidar or radar field of view compared to the larger satellite-based imager pixel size. Also, lidars and radars may retrieve different cloud boundaries depending on the particle size, optical depth, volume density of particles, etc. Differences between remotely-sensed and ground-based cloud properties must be examined carefully without automatically assuming that only one value is correct.

Basic questions include the following:

1. If multiple algorithms are used to retrieve either cloud-top height or cloud-base height, are they consistent with each other? For instance, are LBTM cloud height retrievals consistent with those obtained using the CO₂ slicing method for cirrus?
2. A related question is whether the multiple algorithms results are consistent for various cloud types, such as stratocumulus, thin cirrus, or multiple cloud layers?
3. It has been shown that surface-based lidars and millimeter radars may not determine the same cloud boundaries, due to signal attenuation or the presence of small cloud particles.

If the lidar and radar results do not agree, what is the best set of lidar or radar cloud boundaries to compare with satellite cloud heights?

4. If a final choice of satellite algorithm can be made for each cloud type, what is the most appropriate method for comparing satellite-retrieved cloud heights with surface-based lidars, radars, or ceilometers? Part of this discussion must take into account the autocorrelation length of various cloud types; i.e., the spatial scale of independence of cloud height samples. Information of the spatial scale of cloud types is in the process of being derived from LITE data.

We need to demonstrate that the eventual CERES satellite retrieval algorithms retrieve consistent results for all cloud types, regardless of location, time of day, or synoptic air mass type. Since few cloud retrieval algorithms have operated globally, our desire for consistency is likely to be unfulfilled in the near future. However, the CERES cloud retrieval approach provides a mechanism for algorithms to intercompare results; we will be able to intercompare results for all conditions, day or night. Regional areas with inconsistent results will require further intensive study and algorithm development. It may also point to locations where a field campaign may be required.

Plan #1: Routine (long-term) comparison of Satellite with Ground-Based Observations

Lidar and radar observations provide a measure of horizontal and vertical cloud structure (e.g. Platt et al. 1980; Sassen et al. 1990; Uttal et al. 1995). However, lidars and radars have much finer spatial resolution (on the order of meters) than satellite observations (on the order of kilometers). Comparison of satellite cloud-base and cloud-top heights with ground-based lidar or radar measurements is problematic because of the difference in spatial resolution between the ground-based and satellite sensors. There are two approaches to address this problem. The first approach is to compare the imager pixels closest to the ground site with temporally averaged (perhaps 10 minutes) lidar or radar data. The second approach is to perform a temporal average of the ground-based data over a period of hours and compare with spatially averaged cloud height retrievals (e.g., Baum et al. 1995b). These approaches will be used for all ground-based data used in our validation.

An example is useful to explore the independent nature of ground-based measurements for cloud-height validation. If we assume 12 m/s as a typical low-level cloud velocity and further assume a 500-km cloud spatial scale of independence, the lidar or radar would have to run for about 12 hours to obtain just one sample for satellite validation purposes. During the 12-hour period, some cloud evolution is likely, but this will be accounted for through appropriate temporal averaging. It is also possible that different cloud regimes will be observed during the 12-hour period as the active lidar or radar samples between breaks in the lower-cloud layer and may find a higher cloud layer (i.e., multiple cloud layers). Using this example, a field campaign, such as FIRE, runs for 3 weeks, 24 hours/day, then active lidar or radar would be expected to provide a minimum of $21 \text{ days} \times 2 \text{ samples/day} = 42$ independent samples for validation. This example was for low-level clouds; for high-level clouds, a typical cloud velocity is 25 m/s or higher, which would more than double the number of independent samples we could obtain from ground-based lidars or radars. We also note that a study is underway to investigate cloud spatial scales using LITE data; a preliminary set of autocorrelation scales as a function of cloud type should be available in 1996.

For our purposes, the highest priority set of observations will be those where CERES cloud properties can be compared *routinely* to those obtained at a well-known surface site such as that provided by the Atmospheric Radiation Measurement program. Extended observations will be provided by the ARM sites, but not at all the locations we require according to the categories above. These include a currently operational site (Southern Great Plains, specifically Oklahoma), a Tropical West Pacific site to be operational in 1996 (five islands north of Australia), and an Arctic site (north slope of Alaska) planned for 1997. Data from these sites will provide validation samples continuously for all seasons, for the local background conditions at each site. For low-level clouds, using the assumptions in the example above, each site will provide a minimum of 730 independent sample per year. The important point here is that CERES needs data for comparison over a long time period from sites placed in different cloud regimes. If algorithms are developed or tuned specifically to improve retrievals in one region, problems may occur in different regions. A second, and not inconsiderable, point to mention is that with routine measurements, one should expect that input data structures to change infrequently. That is, we do not have to work the problem of “spin-up” with a new data set involving new data formats and data structures, frequency of measurements, idiosyncrasies, etc. that are common to data collected during infrequent field programs.

For algorithm validation over the ARM sites, NOAA operational data (AVHRR and HIRS) provides 2 retrievals/day (one day, one night) for a total of 365 days/year*2 samples/day = 730 samples/year. Over the United States ARM site, CERES cloud algorithm can be adapted for use with the GOES-8 and GOES-9 imager (1-km resolution) and sounder (4-km resolution) data. Benefits include the ability to incorporate the NOAA network of ceilometers over the United States and other sites in the U.S. that take lidar or radar data continuously (such as Ken Sassen, University of Utah; Tom Ackerman, Penn State). The GOES 15-micron sounder channels can be incorporated in preparation for the eventual MODIS data stream.

In addition to the use of ARM data, surface synoptic observations collected by the NOAA National Meteorological Center (NMC) will be obtained and analyzed daily. The synoptic observations include amount of cloud cover (in octals), type of cloud observed, and also observations of multilayered cloud conditions. The product we are using currently is provided by the National Weather Service every six hours for approximately 100 sites in the United States, and the data are available through McIDAS. These synoptic observations have been used in the “research mode,” but need to be incorporated in a more organized fashion in the TRMM time frame. Part of the difficulty in using surface synoptic reports lies in the data format and extracting the required information. Additionally, routine observations of cloud cover are provided by numerous sites around the globe, but further investigation is needed to determine the best way to incorporate the observations. It would be extremely useful if EOSDIS would make the data available in HDF to the CERES team.

There is also a relatively new effort to compare ground observations of cloud cover with satellite observations using an Automated Surface Observing System (ASOS, Schreiner et al. 1993) over the continental United States. The ASOS ground observations include ceilometer measurements. For validation of cloud-base heights, we note that NOAA has implemented a ceilometer network over the United States. The ceilometers, currently numbering about 500, reside primarily at airports. For clouds below about 4 km, ceilometer measurements accurately determine cloud-base heights (e.g., Miller and Albrecht, 1995). Our understanding is that the hourly cloud-base reports are assimilated into the hourly NWS reports. Further investigation is required to determine what steps would have to be taken to obtain these data and in what form these data are stored. If the CERES cloud algorithm is adapted for use with the GOES data stream, and if we assume that we

can obtain data from 100 ceilometers/day, we could obtain: $100 \text{ ceilometers} \times 2 \text{ samples/day} \times 2 \text{ GOES satellites} = 400 \text{ samples/day}$. Over the course of a year, we could obtain $400 \times 365 = 146,000$ samples/year, of which some fraction would actually contain low cloud base height information.

Long-term cloud boundary statistics could be generated from outside (of EOS) investigators willing to collect lidar, radar, or ceilometer data routinely during TRMM or EOS platform overflights. For instance, we note that investigators at the NOAA Environmental Research Laboratory in Boulder, Pennsylvania State University, University of Utah, and University of Florida in Miami routinely collect radar or lidar data. Their data would be of great use to our effort.

Plan #2: Regional (short-term) comparison of Satellite with Ground-Based Observations

A number of field programs have addressed various aspects of cloud property retrieval. Instrumentation for these campaigns varies widely. It is only recently that radars have begun to complement lidars to determine cloud boundaries. Cloud boundary statistics for FIRE Cirrus II have been presented by Uttal et al. (1995). Existing and future field experiments (FIRE, SCAR, SHEBA, TOGA-COARE, CEPEX, ASTEX, ECLIPS, MCTEX, and others) will provide important validation for their particular climatic and background conditions; however, validation samples over mid-latitude ocean, mountains, deserts, and tropical land are still needed.

The typical field campaign has a duration of a month or less. Some of the drawbacks to using field mission data of short duration are that a.) data formats vary widely; b.) data quality is problematic; and c.) obtaining all the necessary data sets for performing a comparison of ground-based with satellite retrievals may take years from the date of the experiment, and depends greatly on the willingness of the investigators to let go of their data in a reasonable amount of time. The bottom line is that working with short-term field campaigns may be extremely time consuming for relatively little benefit. It would be of great benefit if data from the various campaigns were required to be available in a reasonable time frame, with good documentation and standard data formats.

Plan #3: Validation with Aircraft

With the comparison of satellite to ground-based observations cloud boundaries according to the strategies previously outlined, deficiencies will still exist over midlatitude oceans, mountains, deserts, and tropical land. To fill data-sparse gaps in our sampling, it would make sense to fly an instrumented aircraft such as the ER-2 over those areas in or near North America that most closely resemble these surfaces. From an economic standpoint, it is desirable to perform these aircraft flights over the North American continent instead of deploying internationally. As an example, the ER-2 was used during the SCAR-B experiment over Brazil to provide important data over tropical land.

To estimate the amount of flight time required to obtain 1000 independent validation samples, we show the following example. The ER-2 is assumed to fly at approximately 700 km/hour. For a 500-km spatial scale of independence, we would retrieve about 1.4 samples/hour. Since the ER-2 costs about \$4000/hour for aircraft time, the cost of obtaining 1,000 independent samples is $1000 \text{ samples} \times (500/700) \times \$4000/\text{hour} = \$2.9 \text{ million}$.

Plan #4: Stereoscopic Validation Using GOES-8 and GOES-9 (Lowest Priority of all plans)

Another interesting possibility to consider has been raised through discussions with Paul Menzel and Don Wylie at the Space Science and Engineering Center (SSEC) in Madison, Wisconsin. Previously, when two GOES satellites were flying (GOES-East and GOES-West), some attempts were made to use the imagery from the two satellites to retrieve cloud base and cloud top heights through stereoscopic projections. While the procedure has not been applied to GOES-8 and -9 data yet, both MODIS and CERES would benefit from exploring this technique to derive independent assessments of cloud base and height.

Both a manual and automated method have been used. Don Wylie used a manual procedure to project one image into the other. For each stereo pair, he pulled out about 100 samples. He estimates each stereo pair took between 2-3 hours to analyze. Don used this software to estimate cirrus cloud heights for comparison with the GOES sounder; however, he thinks it should work with any cloud with a well-defined edge. He expects the resolution of the cloud height should be about the same resolution as the imager or perhaps a bit better, so the ultimate resolution we could expect with 1-km imagery would be better than 1 km.

The automated method is a variation of the cloud motion wind vector software. It detects the “motion” of the clouds observed by coincident stereo images remapped into the same projection. The amount of movement is due to the difference in instrument view angle and can be used to determine cloud heights. This technique has never been used to evaluate cloud base, and works best over well-defined clouds. Good navigation of the instrument data is crucial; therefore, manual inspection of the results will be necessary.

The use of stereo pairs has several benefits. First, it can be used with any well-defined cloud type over any surface for which the two images can be superimposed. Second, we can numerous samples for most of the cloud types and surfaces we are interested in. Third, there are other ancillary data sets to verify the cloud heights, such as ceilometers, lidars, and radars at the U.S. ARM site. Drawbacks to this method include the fact that most of the samples will be from the central U.S., where the stereo matching is expected to be the best.

To summarize, progress on this task involving the use of stereoscopic imagery would depend on

- a. modifying the CERES cloud retrieval code to work with imagery from the GOES-8 and 9 satellites.
- b. modifying the existing GOES stereo software to work with GOES-8 and -9.
- c. training people to manually use the software and believe the results.
- d. compare stereo cloud height results with CERES output.

4.2.3.2 Operational surface networks

We anticipate using the following products in our pre-launch activities:

- a. National Weather Service (NWS) global synoptic cloud observations
- b. Ceilometer network (operational over continental U.S.)

- c. Automated Surface Observing System (ASOS), installed on the National Environmental Satellite Data and Information Service VAS data utilization center in Washington, D.C.

4.2.3.3 Existing satellite data

A list of the satellite data sets used in pre-launch activities are:

- AVHRR (NOAA-9, 11, 14, plus new platforms)
- HIRS (NOAA-9, 11, 14, plus new platforms)
- GOES-8 and GOES-9
- ER-2 MAS and lidar (not satellite data, but close enough for this purpose)
- LITE

4.2.4 Post-launch Activities

4.2.4.1 Planned field experiments and studies

The same approach as presented in Section 4.2.3.1 will be followed for post-launch activities. Since the cloud retrieval properties for the imager data are not going to be saved as an actual data product, we will save selected regions daily for validation activities. The Version 1 list of selected regions includes both poles, North and South America, the coasts of Europe, N. America, and S. America (persistent stratus regimes), the Tropics (Tropical ARM site) to include Australia, and a few other sites. These subsetted data sets will be produced through EOSDIS and detailed analysis will be provided primarily by the CERES Co-Investigators.

4.2.4.2 New EOS-targeted coordinated field campaigns

With the comparison of satellite to ground-based observations cloud boundaries according to the strategies previously outlined, deficiencies will still exist over midlatitude oceans, mountains, deserts, and tropical land. To fill data-sparse gaps in our sampling, it would be beneficial to plan field campaigns for these areas.

4.2.4.3 Needs for other satellite data

The fastest method to collect a set of global cloud boundary data could be to employ satellite-borne lidar/radar observations, such as from LITE. LITE has flown once but the usefulness of that data for CERES is limited since GOES-8 was still not operational at that time. Also, NOAA-11 ceased operation 2 days into the launch of LITE, so there are no coincident NOAA-11/LITE observations. Unfortunately, no more than 2 LITE/NOAA-12 coincidences were found because the coincidences occurred near the terminator at high latitudes, and LITE was usually not taking data near

the terminator. While few comparisons could be made during the first flight of LITE, a future mission could provide invaluable measurements of global cloud boundaries.

A useful future mission would be to fly a satellite with an imager, such as MAS, with a lidar such as LITE or a millimeter radar (35 or 94 GHz). With the assumption that a spacecraft is moving at 7 km/s, we could obtain roughly one sample/minute. Under this scenario, we could obtain roughly $1 \text{ sample/min} \times 60 \text{ min/hour} \times 24 \text{ hours/day} = 1440 \text{ samples/day}$, or 525,600 samples/year with global coverage. While the total number of samples looks promising, the number of samples/category may not be sufficient, depending on the orbit of the platform.

4.2.4.4 In-situ measurement needs at calibration/validation sites

4.2.4.5 Needs for instrument development

4.2.4.6 Geometric registration site

4.2.4.7 Intercomparisons (multi-instrument)

4.2.5 Implementation of validation results in data production

4.2.5.1 Approach

We anticipate that validation of cloud properties will take place at the CERES SCF or at the outside investigator home institutions. While some of the global mapping functionality can be automated, most of the effort described in this document requires interaction with an investigator. The investigator will need ready access to cloud boundary information from each of the ARM sites or other sites that are operationally providing cloud boundary information, as well as access to the subsetted data sets of retrieved cloud properties.

4.2.5.2 Role of EOSDIS

EOSDIS will have an important but limited role in this process. For the retrieved cloud parameters listed in Table 4.4-4 of CERES Subsystem 4.4, entitled "Convolution of imager cloud properties with CERES footprint point spread function", the volume of one hour of processed imager data is approximately 600 MB. These retrievals are not a product, but are subsequently convolved with CERES footprints. It would be impractical to save all the output from processing each hour of imager data. We propose to subset the output data stream by choosing a number of regions around the globe that are useful for validation purposes.

We would like for the data center processing CERES data to routinely save the data for the prescribed set of regions designated by the CERES team. The saved data should be considered a temporary product. Cloud boundary data from the sources listed in this document should also be available through EOSDIS. We request that NOAA NMC surface synoptic observations be made available in an EOS standard data format such as HDF.

4.2.5.3 Plans for archival of validation data

4.2.6 References

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4.2.7 List of Acronyms

ARM	Atmospheric Radiation Measurement Program
ASOS	Automated Surface Observing System
ASTEX	Atlantic Stratocumulus Transition Experiment
AVHRR	Advanced Very High Resolution Radiometer
ECLIPS	Experimental Cloud Lidar Pilot Study

FIRE	First ISCCP Regional Experiment
GOES	Geostationary Orbiting Environmental Satellite
HIRS	High-resolution Infrared Radiometer Sounder
ISCCP	International Satellite Cloud Climatology Experiment
LBTM	Layered Bispectral Threshold Method
LITE	Lidar in Space Technology Experiment
MAS	MODIS Airborne Simulator
MCTEX	Marine Continental Thunderstorm Experiment
MODIS	Moderate resolution Imaging Spectrometer
NMC	National Meteorological Center
SASS	Subsonic Assessment Program
SHEBA	Surface HEat Budget in the Arctic
VIRS	Visible and Infrared Scanner

SUMMARY OF CERES VALIDATION OF IMAGER CLOUD-TOP AND CLOUD BASE HEIGHTS

DATA PRODUCTS/PARAMETERS

- o Parameters: Cloud-top and cloud-base heights for both single- and multiple-layered clouds

Product: CERES SSF

MISSIONS

- o TRMM, EOS AM-1, & EOS PM-1

APPROACH:

- o First develop global and regional maps of retrieved cloud heights
- o Show that global and regional analyses indicate consistent results moving from ocean to land, day to night, snow to water, desert to water, etc.
- o Once results are consistent, compare retrieved cloud boundaries with ground-based, other satellite-based, or aircraft-based data of cloud boundaries (most appropriate for stratiform clouds)
- o Comparisons of simultaneous retrievals from multiple satellites, aircraft and satellite, or surface with satellite

PRELAUNCH

- o Compare cloud boundary data from field programs with satellite retrievals
- o Compare surface synoptic observations with satellite retrievals of single and multilevel cloud occurrences

SUMMARY OF CERES VALIDATION OF IMAGER CLOUD-TOP AND CLOUD BASE HEIGHTS

POSTLAUNCH

- o Increase number of long-term monitoring sites to include midlatitude oceans, mountains, deserts, and tropical land
- o Develop field programs over surface types where little if any data currently exist, such as deserts
- o Perform quick-look global and regional analyses of cloud boundary products
- o Compare CERES cloud boundary retrievals with validation sites

EOSDIS

- o Perform subsetting of processed full-resolution CERES imager data stream
- o Archive validation site cloud boundary data